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Predicting strain localization in high porosity materials

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ABSTRACT

Rudnicki and Rice (1975; RR75) proposed that strain localization in pressure-dependent materials could be modeled as a bifurcation from homogeneous deformation, because of a constitutive instability in an initially uniform material undergoing inelastic deformation. Using a continuum approach, details of the material mesostructure were not specified, but rather enter through the choice of continuum constitutive relation. Although RR75 had dilatant, low porosity rocks in mind, they used a sufficiently general constitutive relation (inelastic deformation depends on first and second invariants of stress) to enable the localization framework to be applied to a variety of materials. Of relevance, here is the application to porous materials. For example, Aydin and Johnson (1983) extended the RR75 framework to examine compactant shear bands in high porosity sandstone. Olsson (1999) proposed that the RR75 framework could be used to predict compaction bands in high porosity sandstone. Thhis study employs the RR75 framework to interpret experimentally observed strain localization in various porous materials, including high porosity sandstone and aluminum foam. Two closed-cell aluminum foams (Alporas and Cymat) were tested under uniaxial tension or compression. All 37 specimens experienced strain localization. Under compression, bands consisted of intense compaction via cell collapse, combined with notable shear offset. During tension tests, a roughly planar zone of localized dilation (extension) preceded formation of a through-going fracture. Observed band angles (angle between band normal and direction of maximum compression/minimum tension) were calculated and compared with predictions (all angles below are in degrees). Under uniaxial compression, observed bands in Alporas were oriented at 8–20 and predictions were 20–30; for Cymat, observed band orientations were 10–23 and predicted angles were 7–19. For Alporas foam under uniaxial tension, observed band angles were 71–88, compared to predicted angles of 63–74. For all specimens, the average difference between the observed and predicted angles was 8. For uniaxial compression, the predicted angle was generally higher than the observed angle; for uniaxial tension, the predicted was typically lower than the observed. Possible causes for the discrepancies will be discussed. For comparison, results are provided from true triaxial testing of high porosity Castlegate sandstone (details presented in the MD Ingraham discussion), which exhibited two localization modes: shear bands and compaction localization.Predicted shear band angles demonstrated reasonable agreement with observed angles. At 30–60 MPa mean stress, observed band angles were 48–66; predicted angles were typically <3 of observed. At 90 MPa mean stress, observed band angles were 23–57; the average difference between predicted and observed angles was 14. At 120–150 MPa, a diffuse zone of compaction localization occurred and predicted angles were generally in poor agreement with observed angles; likely causes for this will discussed. In summary, this work examined application of the RR75 localization framework toward predicting strain localization in diverse porous materials under various loading conditions (uniaxial tension, uniaxial compression, true triaxial compression). For all the materials and loading conditions considered here, when failure consisted of a well-defined band of localized strain, the predicted angles demonstrated reasonable agreement with observed angles.